

B Hadron Production and $b\bar{b}$ Correlations in Z^0 Decays at SLD

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We present results of three SLD analyses: our final determination of the rate of gluon splitting into $b\bar{b}$, an improved measurement of the inclusive b quark fragmentation function in Z^0 decays, and a preliminary first measurement of the energy correlation between the two leading B hadrons in Z^0 decays. Our results are obtained using hadronic Z^0 decays produced in e^+e^- annihilations at the Stanford Linear Collider (SLC) between 1996 and 1998 and collected in the SLC Large Detector (SLD). In this period, we used an upgraded vertex detector with wide acceptance and excellent impact parameter resolution, thus improving considerably our tagging capability for low-energy B hadrons.

1 Introduction

The vertex representing a gluon splitting into a $b\bar{b}$ pair, $g \rightarrow b\bar{b}$, is a fundamental component of QCD, but the contribution of this vertex to physical processes is poorly known, both theoretically and experimentally. In high-energy e^+e^- annihilation the leading-order process containing this vertex is $e^+e^- \rightarrow q\bar{q}g \rightarrow q\bar{q}b\bar{b}$; information on $g \rightarrow b\bar{b}$ can thus be obtained by studying $e^+e^- \rightarrow \text{hadrons}$ events comprising four jets, with two of the jets identified as b or \bar{b} . We define the rate $g_{b\bar{b}}$ as the fraction of $e^+e^- \rightarrow \text{hadrons}$ events in which a gluon splits into $b\bar{b}$. The measurement of $g_{b\bar{b}}$ is difficult experimentally since the rate is intrinsically low and the backgrounds from $Z^0 \rightarrow b\bar{b}$ events are two orders of magnitude larger. In addition, the B hadrons from $g \rightarrow b\bar{b}$ have relatively low energy and short flight distance and are difficult to identify using standard tagging techniques. We present a world's best measurement of $g_{b\bar{b}}$ using our vertexing ability to find low energy B hadrons.

According to the factorization theorem, the heavy quark fragmentation function can be described as a convolution of perturbative and non-perturbative effects. For the b quark, the perturbative calculation is in principle understood, and the non-perturbative effects have been parametrized in both model-dependent, and model-independent approaches.¹ The most sensitive experimental determination of the fragmentation function is expected to come from a precise determination of the B hadron energy distribution. We have previously reported the first measurement of this distribution over the entire allowed kinematic range;² here we update that result and exclude many models and place stringent bounds on the form of the distribution.

Extending the fragmentation analysis to look at the energy correlation between the two B hadrons in a $Z^0 \rightarrow b\bar{b}$ event further constrains theoretical work. It can provide a direct test of the QCD factorisation theorem,³ and further probe phenomenological models. For example, models that accurately predict the inclusive energy distribution might not find the correct correlation, and vice versa. We present an analysis that measures the correlation and compares it with a leading order QCD calculation.

2 Selecting B Decay Vertices

A general description of the SLD detector can be found elsewhere, as can the trigger information and selection criteria for $Z^0 \rightarrow \text{hadron}$ events.^{4,5} The B sample is selected using topologically reconstructed secondary vertices based on the detection and measurement of charged tracks.⁶ To reconstruct the secondary vertices, the space points where track density functions overlap were found in three dimensions. Only vertices that are significantly displaced from the IP were considered to be a possible B -hadron. With SLD's good track impact parameter resolution and precisely known interaction point, the vertex finding gives excellent b -tagging efficiency and purity. In particular, the efficiency is good even at low B -hadron energies, which is especially important for detecting $g \rightarrow b\bar{b}$, and for shape resolution of the fragmentation function. The mass of the reconstructed vertex, M_{ch} , is calculated by assigning each track associated with it, the charged-pion mass. Because of the tiny SLC IP error and the excellent vertex resolution, the transverse momentum P_t of tracks associated with the vertex relative to the line joining the IP and the secondary vertex is well-measured. The mass of the missing particles can then be partially compensated by using P_t to form the " P_t corrected mass", $M_{P_t} = \sqrt{M_{ch}^2 + P_t^2} + |P_t|$.

3 The Rate of Gluon Splitting into $b\bar{b}$ Pairs

Candidate events containing a gluon splitting into a $b\bar{b}$ pair, $Z^0 \rightarrow q\bar{q}g \rightarrow q\bar{q}b\bar{b}$, where the initial $q\bar{q}$ can be any flavor, are required to have 4 jets (Durham algorithm, $y_{cut} = 0.005$). A secondary vertex is required in each of the two jets with the smallest opening angle in the event, yielding 1514 events. This sample is dominated by background ($S/N \sim 1/10$), primarily from $Z^0 \rightarrow b\bar{b}g(g)$ events, and events with a gluon splitting into a $c\bar{c}$ pair.

In order to improve the signal/background ratio, a neural network technique is used. Nine observables are chosen for inputs to the neural network. The inputs include the P_T -corrected masses of the vertices and the angle between the vertex axes: b jets have higher P_T -corrected mass than c/uds jets; many $Z^0 \rightarrow b\bar{b}$ background events have one b -jet which was artificially split by the jet-finder into 2 jets that tend to be collinear. The neural network is trained using Monte Carlo samples of 1800k $Z \rightarrow q\bar{q}$ events, 1200k $Z \rightarrow b\bar{b}$ events, 780k $Z \rightarrow c\bar{c}$ events and 50k $g \rightarrow b\bar{b}$ events. A cut on the neural network output of > 0.7 keeps 79 events in the data, with an estimated background of 41.9 events. Using this and the estimated efficiency for selecting $g \rightarrow b\bar{b}$ splittings of 4.99% yields a measured fraction of hadronic events containing such a splitting of:

$$g_{b\bar{b}} = (2.44 \pm 0.59(stat.) \pm 0.34(syst.)) \times 10^{-3} \quad (1)$$

The result is consistent with previous results and the QCD prediction⁷ of 1.75×10^{-3} .

4 The Inclusive b Quark Fragmentation Function

Candidate events for this analysis were found by requiring a secondary vertex in an event hemisphere with each hemisphere of the event being treated independently. Placing the condition that the vertex must have an $M_{pt} > 2$ GeV and a distance from the I.P. > 0.1 yields a B hadron sample of 42,093 from the data with an estimated purity of 98.2%. Assuming all the tracks associated with the vertex are pions we calculate the charged track energy, E_{ch} , and the total momentum vector \vec{P} of the B vertex; we must then find the energy of particles missing from the vertex. We assume $P_{Tmissing} = P_{Tcharged}$ and $M_B = 5.26 \text{ GeV}$ leading to an upper bound on the missing mass M_0 : $M_{0max}^2 = M_B^2 - 2M_B\sqrt{M_{ch}^2 + P_t^2} + M_{ch}^2$. The true missing mass M_0^{true} is often rather close to M_{0max} , and we use the latter as an estimate of M_0^{true} . We can then solve for the longitudinal momentum of the missing particles using kinematic considerations,

and hence the missing energy from the vertex, E_0 . The B hadron energy is then $E_B = E_{ch} + E_0$. Since $0 \leq M_0^{true} \leq M_{0max}$, the B energy is well-constrained when M_{0max} is small. For this reason, in order to obtain good energy resolution, we cut events from our sample using a value of M_{0max}^2 that depends on E_B to achieve a B selection efficiency nearly independent of x_B . A total of 4,164 vertices were found after all cut criteria, with an estimated purity of 99.0%. The full kinematic range is covered by these events.

After background subtraction, the distribution of the reconstructed scaled B hadron energy is compared with several heavy quark fragmentation models. Within the context of the JETSET Monte Carlo the Bowler, Lund, and Kartvelishvili models are consistent with the data as is the stand-alone UCLA generator. We also compared the data with a set of *ad hoc* functional forms of the x_B distribution in order to estimate the variation in the shape of the x_B distribution. Of those we tested, only the Peterson function, two *ad hoc* generalizations of the Peterson function and an 8th-order polynomial are consistent with the data.² We use the eight consistent fragmentation models and functional forms to unfold the raw data distribution for selection efficiency and bin migrations. Their average is taken as the central value in each bin and the RMS value as the model dependent error. The fully corrected data are shown in Figure 1.

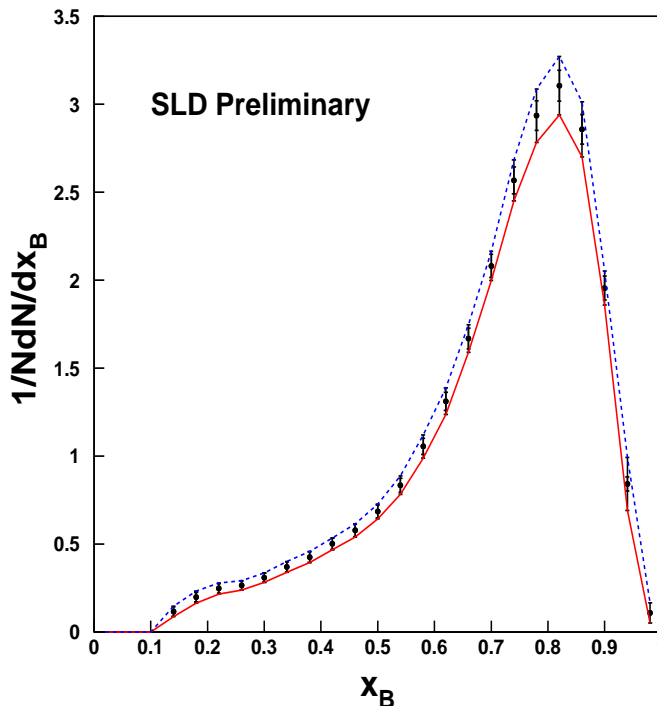


Figure 1: The corrected single inclusive weakly decaying B hadron energy distribution. The points represent the data, and the envelope is our total error.

5 The Two Dimensional $B\bar{B}$ Energy Distribution and Correlation

The previous analysis has placed considerable constraints on the form of the b fragmentation function, and on phenomenological models. SLD, however, can go further and look at the correlation between the 2 leading B hadrons. Events are selected by requiring that exactly two secondary vertices are found in different jets (Durham algorithm, $y_{cut} = 0.015$). Either vertex is required to have an $M_{pt} > 2$ GeV and the same (or otherwise) vertex, is required to be separated from the I.P. by > 0.1 cm. An upper limit on M_0 of the remaining sample ensures an energy resolution better than 20%. A cut on the angular separation between the two decay vertices avoids the problem that sometimes a genuine vertex is split into two separate candidates. After all selection criteria we have 19283 events in the data in which both the B and \bar{B} are reconstructed with an estimated purity and efficiency of 99.6% and 36.6% respectively. We

group these events in bins of $\cos\phi$ where ϕ is the angle between the two vertex axes. By taking moments of the 2-dimensional energy distribution we have a measure of the correlation between the two hadrons. Within each bin we calculate the double moments $D_{ij}(i, j = 1, 2, 3)$. We use our Monte Carlo to correct the data for selection efficiencies and detector effects. In order to compare with the QCD calculation we take a ratio and calculate normalise the D_{ij} to D_{11} . The ratios of these moments, P_{ij} are compared with a leading order QCD calculation in Figure 2.

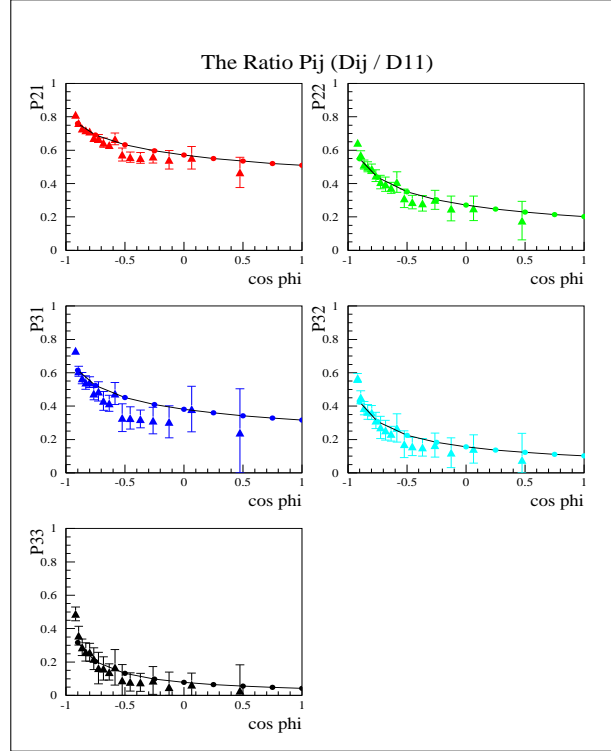


Figure 2: Ratio of the double moments P_{ij}/P_{11} of the 2-dimensional B hadron energy distribution. Data are shown as points with stat. error bars only. A leading order QCD calculation of the ratios are shown as solid lines.

6 Conclusion

We have presented the results of three analyses, all of which make use of SLD's exceptional B-tagging performance. Our final determination of the rate of gluon splitting into $b\bar{b}$ pairs per hadronic Z^0 decay, $g_{b\bar{b}}$, is a world's best: $g_{b\bar{b}} = (2.44 \pm 0.59(stat.) \pm 0.34(syst.)) \times 10^{-3}$. We have updated our measurement of the inclusive weakly decaying B hadron energy distribution and exclude many models of b quark fragmentation. We obtain a precise measurement of the average scaled B hadron energy: $\langle x_B \rangle = 0.710 \pm 0.003(stat.) \pm 0.005(syst.) \pm 0.004(model)$. We have a first measurement of the energy correlation between the leading B hadrons in Z^0 decays, the results of which are consistent with a leading order QCD calculation.

References

1. For a fuller discussion of these approaches and relevant references, see 2.
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